Device for Solar Powered Mobile Charging and Water Purification in Bus Terminus with AI Monitoring

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Keywords: Smart Solar Street Lamp, Simulation-Based Approach, Rainwater Harvesting, AI-Based Monitoring, Energy Efficiency, Sustainability.

Abstract: This article demonstrates the simulation model for a smart solar street lamp, using a rainwater collection module and an AI monitoring module for enhanced energy usage and sustainability. Well, they show that they are able to simulate the maximum output that solar panels can deliver in terms of power, while at the same time they are able to gather the water that falls on the panels and direct it towards a virtual storage system – making it sustainable for human use (drinking) and also environmental use (irrigation). Under different environmental conditions, simulation tools are used to validate the energy efficiency of the system, the effectiveness of water collection, and the operation reliability. An AI-based simulation model is used to monitor the best way of solar energy output, battery health, water levels, and environmental parameters. Machine learning algorithms which are used by the AI system to emulate anomaly detection, energy efficiency prediction and maintenance predictions to ensure the reliability and decision-making. The research conducted to simulate this assessment is a critical case study that shows valid data for the practicality of the technology and efficiency of a modular solar-water-smart streetlight. These preliminary findings are conducted toward future applications in real life, in particular for green energy and smart infrastructure projects.

1 INTRODUCTION

Due to the growing demand for green energy sources, solar-powered streetlights have emerged as one of the most widely implemented technologies today (Sutopo et al., 2020; Hossain et al., 2022). But the system is inefficient due to limitations such as dust settle on solar panels and improper energy storage (Cheng et al., 2020; Anguraj et al., 2022). This project provides a simulated model for an AI-based solar powered streetlight with a rainwater harvesting system to mitigate these disadvantages (Ahmed et al., 2024; Anitha Vijayalakshmi et al., 2025). The structure on the roof aims for unlimited exposure to solar radiation and at the same time transport rainwater in a harvesting system for both modeled storage and filtration. For that, the technique provides the best possible energy utilization and saved water and thus provides a multifunctional and a sustainable technology, both urban and agronomics. You are powered by an AI-enabled monitoring system that provides real-time insights into solar generation, battery health, water levels, and weather conditions (Ganvir et al., 2024; Mehta & Bhalla, 2024). The system is programmed to leverage machine learning programs to identify anomalies, then predict energy consumption, and through these predictions to autodetect system performance without the cost of installation (Mohanty et al., 2024; PK & KRS, 2024). Simulation also confirms the efficacy of excess solar energy in secondary applications like charging mobility and small auxiliary power load and proves that smart energy management can be a reality (Michail, 2021; Tran et al., 2021). The simulation study provided here validates the proposed urban smart solar streetlight infrastructure and demonstrates to provide compelling insights on system feasibility, sustainability, and relevancy towards real-life implementation. The innovation specially focuses on improving the reliability and functionality of the accumulated solar-based infrastructure by using AI-assisted performance improvement resource planning; and the milestone is indeed an important step towards the facilitation of green energy

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technology leading to sustainable energy systems (Meem, 2023; Shanmugasundaram et al., 2025).

2 PROBLEM IDENTIFICATION

Traditional solar streetlight systems never achieved maximum energy potential of the solar panels as their main objective is light (Cheng et al., 2020; Sutopo et al., 2020). As these systems lack an effective energy management system, surplus solar energy generated throughout the day is wasted (Archibong et al., 2020; Chaudhary et al., 2022). Overall efficiency of the system is reduced since the surplus energy is wasted instead of channeling or storing it for future use. This solar underemployment makes available a core lacuna in utilizing the utmost potential of solar energy, which could otherwise be diverted towards different public benefits. The inefficiency of traditional solar streetlights on cloudy and foggy days is a core weakness (Hao et al., 2022; Islam et al., 2021). Solar panels need direct sunlight to transfer energy, but sunlight that falls on the panels falls immensely short under overcast, fog, or rainy weather. Since there is not enough penetration of light because of thick cloud cover, power generation is significantly decreased. The underlying cause of wasteful utilization of solar energy has not been resolved even after implementing innovations such as IoT integration and smart monitoring systems for the improvement of solar street lights (Dwiyaniti et al., 2022; Khemakhem & Krichen, 2024).

3 METHODOLOGY

3.1 Design

The designed multi-purpose rainwater harvesting solar streetlight that will overcome the drawbacks of traditional solar streetlights by efficient use of sun rays and creative water management. Conical roof of the building has a two-way advantage: it allows efficient collection of rainwater and minimizes the slope of solar panels for improved energy absorption. Compared to traditional flat-panel designs, the cone's inclined plane allows the solar panels to be installed at angles, optimizing sunlight captured throughout the day. Particularly in regions with fluctuating solar conditions, the design greatly improves energy harvests by minimizing losses and maximizing system efficiency. With the water collection routed to a central storage tank beneath the pole, the cone is a rainwater harvesting device. As a reservoir for water, the bottom ensures that water is collected and stored in such a way that it is suitable for public sanitation, irrigation, or consumption. A filter system can be provided to enhance performance and have the collected rainwater ready for different uses by the community.

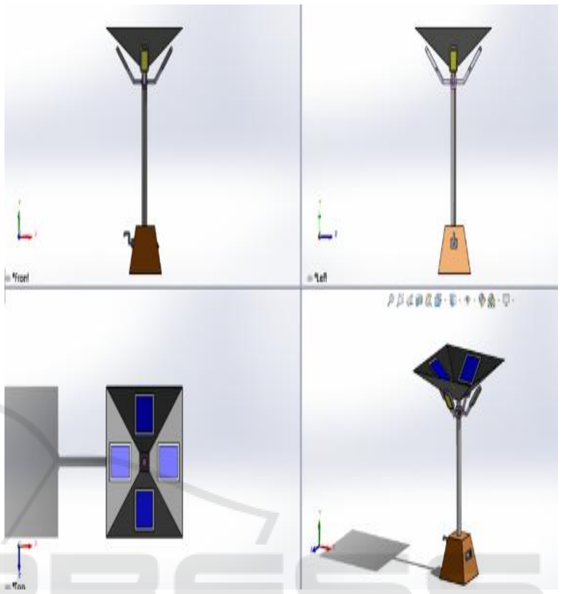

Figure 1: Design.

3.2 Components

3.2.1 Solar Panel

The project discusses the four-piece 12V, 25W solar panel which is proposed for use in this multi-purpose solar streetlight with rainwater harvesting to provide maximum power output, thereby improving energy efficiency and sustainability. The solar panels are positioned on top of a cone structure enabling maximum sun absorption during the day. It can even use solar power efficiently to produce electricity when it is stored in a battery pack and used at night. The entire system has a capacity of around 100W A combination of solar power and enables a 247 operation of an outdoor street light even in cloudy weather. Incorporating a rainwater collector mechanism, the cone structure performs two jobs in one, channelling the rainwater that settles into a vessel at the bottom of the pole. To make that water pressurized and can be used at the place of drinking or public hygiene, you need to set up a filtration plant.

3.2.2 Solar Charge Controller

In order to have effective control and use of power produced by four 12V, 25W solar panels, a 12V solar charge controller must be there. In order to make the energy storage system long-lasting and work effectively, the solar charge controller avoids deep draining, overcharging, and voltage fluctuation in the battery. With a bid to reduce energy wastage and maintain a continuous power supply of electricity to the LED streetlamp as well as other establishments like water treatment facilities or charging facilities, it controls the supply of electricity from the solar panels into the battery storing facility. By delivering the maximum power output by the solar panels, the PWM (Pulse Width Modulation) or MPPT (Maximum Power Point Tracking) technology of the solar charge controller delivers maximum energy conversion efficiency. As it enables the maximum energy to be stored and harvested, the feature proves useful on rainy and cloudy days when there is little or no sun exposure. In order to avoid draining back of battery to the panels at night, the controller further deactivates the reverse flow of current. For smooth and uninterrupted operation of the streetlight system, it can also have a digital display for real-time measurement of battery voltage, charging condition, and load current. The system is highly sustainable and dependable streetlighting solution because it possesses a good solar charge controller that is also energy efficient, prolongs the battery lifespan, and provides a steady power supply.

3.2.3 Charger Converter

12V charger converter to take advantage of excess energy offered by four 12V, 25W solar panels to charge cell phones. The solar panels collect the energy from the sun during the daytime and charge a battery unit. A solar charge controller controls the battery unit not to overcharge and to deliver maximum transfer of power. For the purpose of converting 12V DC voltage of the battery into the required charging voltage of cellular phones and other low-voltage electrical appliances (usually 5V DC), the charger converter is required. The unit is equipped with an onboard DC-DC step-down converter, i.e., 12V to 5V USB charger module, that supplies stable and consistent power output to enable safe and efficient charging of the devices. For application in sparsely populated towns with poor power supply, rural areas, and spaces, the function is quite useful. It facilitates smooth functioning in the supply of energy being provided by solar panels to mobile use charging points to drive the supply of electricity and facilitation of use of renewable energy. Through its integration of energy storage, cell phone charging, and road lighting, the building optimizes the harvesting of solar energy and is an exemplar of a larger functional system that provides intelligent and sustainable infrastructural services.

3.2.4 Battery

To provide efficient storage and utilization of energy, the proposed multi-purpose solar streetlight with rainwater collection system is equipped with a 12V, 100Ah deep-cycle battery. The system requires a strong and reliable battery to save excess solar power during the day since the system is comprised of four 12V, 25W solar panels. Even during rainy and cloudy days when the solar power is low, the stored solar energy in the battery gives an uninterrupted supply of power to the LED streetlight and mobile charging system. The best battery for this application is a deep-cycle lead-acid or lithium-ion battery since it can be recharged and discharged time and again without any loss of efficiency and without causing any damage to the battery, yielding long-term reliability and life. With proper regulation of power input to prevent deep discharge and overcharging, the solar charge controller (12V, 10A) prolongs battery life. The chosen 12V, 100Ah battery can provide power to further accessories such as public charging stations and powering the streetlight day and night.

3.3 Sensors

3.3.1 ACS712 Sensor

The major component of this AI-based monitoring mechanism in simulated solar streetlight, defines as ACS712 current sensor. Figure 1 shows a real-time data connection with a meter sensor that will read the flow of current towards the load/battery from the solar inverter. The ACS712 is based on Hall-effect sensing principles, in which the passage of an electrical current produces an associated magnetic field that is translated into a voltage signal that we can measure. Staying updated on active output from the solar panels, the setup can analyze solar efficiency, battery capacity, and consumption trends. The AI surveillance system employed machine learning algorithms to analyze the unprocessed data collected from the ACS712 sensors and detect power flow anomalies, overcurrent conditions, and inefficiencies in the system. Abnormal drops in current are detected, which could be due to solar panel aging, wire failure, or deteriorating battery performance. In another example, the AI system can send warnings and predictive maintenance tasks upon overcurrent or short circuiting to avoid risk of system failure. The integration of the ACS712 sensor also adds intelligence to the solar streetlight with intelligent monitoring, real-time diagnostics, improved energy usage and more reliable systems. The simulation also allows us to experiment with the performance of the sensor in tracking solar energy flow and power management under different environmental and operational conditions, and therefore it is an essential tool for optimizing sustainable urban and rural lighting systems.

3.3.2 State of Charge (SOC) Sensor

SOC (State of Charge) sensor is the main component of the AI-based monitoring system of the solar streetlight simulation and accurately measures the charge and health of the battery. SOC sensor estimates how much battery capacity is left in time, making sure energy can be used, also prevents overcharging or deep discharge that may shorten the battery life. It does this either through voltage-based estimation or coulomb counting or machine learning algorithms to accurately estimate the cycles of charge-discharge of the battery. Its SOC monitoring integration optimizes energy management for a longer battery life and safer operation of solar-powered lights. The SOC sensor data is monitored by predictive models in detecting charging inefficiencies, unexpected drop-offs, and impending battery failure in an AI-based monitoring system. It can foresee battery performance patterns and identify their deterioration or maintenance indicators based on the AI platform. Moreover, the smart power distribution algorithms use the SOC information to evenly distribute power so that the solar power stored can be used efficiently for street lights, mobile charging and the rain water filtering system. Various aspects of solar-powered infrastructure can be simulated through simulation-based analysis, such as varying weather conditions, varying energy loads, and varying patterns of charging → SOC status becomes an important factor towards establishing sustainable, intelligent and autonomous solar-powered infrastructure.

3.3.3 Ultrasonic Water Level Sensor (HC-SR04)

One of the important sensors of the artificial intelligence-based monitoring system of simulated rainwater harvesting solar streetlight is the Ultrasonic Water Level Sensor (HC-SR04). To use the harvested water for drinking water purification, irrigation, and public use, the module is used to sense and monitor the water level that is stored in the rainwater storage tank. The HC-SR04 works based on the ultrasonic waves, which sends out a high-frequency sound wave through the air, which reflects off of the water level and back to the sensor. By processing the time of echo return, it can monitor storage capacity and water level in real time. The water level is continuously checked against the HC-SR04 sensor in identification of low levels of water, overflow hazards and outsider usage with an integrated AI powered IP cloud based surveillance system. AI systems are used to analyze past history of water level movement as per trends for analyzing likely consumption in future so that water is fitfully controlled without any wastage. Moreover, the system also can generate alerts and performing automated control actions like turning on a water pump when a water level drops below a defined threshold or closing an inlet valve when the tank nears-to-full. Simulation is used to model and optimize the performance of the rainwater harvesting system for different weather, rainy patterns and water use conditions. The system is therefore not only sustainable, resource conserving and independent, but it is also a smart choice for urban as well as rural infrastructure with the incorporation of HC-SR04 sensor and AI surveillance.

3.3.4 TDS (Total Dissolved Solids) Sensor

One of the key sensors in the AI-based monitoring system of the simulated solar streetlight rainwater harvesting, monitoring the quality of water stored for drinking, irrigation and other public use is that of the TDS (Total Dissolved Solids) sensor. The sensor measures total dissolved solids, a measure of minerals, salts, and impurities, in harvested rainwater. It operates on the principle of the conductivity of water, which increases with increased dissolved material. Continuously monitored TDS is maintained by the system to ensure its drinking water is safe and complies with quality. As soon as TDS sensor readings are available in an AI system, machine learning algorithms are utilized to recognize trends of contaminants in the water, predicting filter schedule maintenance, and generating real-time water quality reading. The AI system may be programmed to provide automatic alerts in case TDS levels go beyond safety limits, which may activate warning or filtration or purification systems. It can also scan historical trends to determine the expected changes in water quality as a function of climate variables including rainfall trends, and storage periods. Using simulation testing, the various scenarios of contamination and the models of filtration efficiency can be analysed and the most sustainable rainwater harvesting system designed and optimised for self-sufficient water management. The incorporation of the TDS sensor with AI-based monitoring ensures that the solar streetlight system not only promotes public health but also water conservation and better ecological conditions, distinguishing it as unique and adaptable infrastructure for cities.

3.3.5 DHT22 (Digital Temperature & Humidity Sensor)

The DHT22 (Digital Temperature & Humidity Sensor) is an important part in the AI monitoring system of simulated solar streetlight with rainwater harvesting to provide real-time reading of environmental conditions. This sensor can provide accurate temperature and humidity measurements which is important for measuring solar energy generation and rainwater harvesting efficiency. Using high-accuracy digital outputs, DHT22 works on principles of a capacitive humidity sensor, and a thermistor. By continuously measuring temperature changes and humidity in the air, the system could assess how weather acted on the efficiency of its solar panels and its ability to collect water. This is where the AI-monitoring system comes on board and the DHT22 sensor data is filtered through ML algorithms to check the performance of the system on varying weather conditions. Solar Panels Efficiency Management: The AI system can detect efficiency losses in solar power panels due to high temperature and adapt energy management to optimize the battery usage. Similarly, humidity levels help analyze if it will rain, so rainwater collection systems are not out of service. By utilizing both historical weather data and real-time sensor data, the AI model is able to forecast trends in solar energy generation as well as water storage capacity, ultimately leading to enhanced reliability and sustainability of the system. As such, through simulation analysis, different climate conditions can be modelled, creating a more robust smart solar streetlight under changing environmental conditions. It creates a good infrastructure tool for monitoring climate with renewable energy optimization, resource minimization through AI based user friendly platform integrated with DHT22 sensor for sense detection and monitoring.

3.4 Raspberry Pi 4

The AI-based monitoring system of the rainwater-harvesting solar streetlight simulator has a Raspberry Pi 4 Model B as the central processing unit. Being a key element in system performance improvement, it is responsible for sensor data collection, AI-based anomaly detection, and cloud remote monitoring. Need the calculation power to handle real-time sensor data from the ACS712 current sensor, battery SOC sensor, HC-SR04 water level sensor, DHT22 temperature sensor, PIR motion sensor, TDS water quality sensor, quad-core ARM Cortex-A72 processor (1.5 GHz)+4GB/8GB LPDDR4 RAM. The Raspberry Pi's 40-pin GPIO interface makes it easy to connect a variety of sensors to ensure monitoring of solar generation, battery performance, water levels and weather. Raspberry Pi 4 supports built-in Wi-Fi (802.11ac) and Gigabit Ethernet that allows streaming of data to cloud interfaces in real-time like firebase, thingspeak or AWS IoT for remote monitoring and predictive analysis. Other features like USB 3.0 ports and microSD or SSD expandable storage make it suitable for efficient data logging and AI model execution. Machine learning libraries such as TensorFlow and OpenCV also support Raspberry Pi 4 for anomaly detection and predictive maintenance to ensure system reliability. Raspberry Pi 4 can handle real-time conditions though simulation-based analysis in an optimized manner promotes to system performance, energy management, and looks after the sustainability of the smart solar streetlight system. Thus, all these with the integration of edge computing, AI monitoring, along with IoT connectivity make Raspberry Pi 4 Model B a powerful and efficient monitoring system that is highly scalable, and provides smart infrastructure for urban and rural amenities to generate a strong infrastructure.

3.5 Circuit Diagram

Below Figure 2 is a circuit diagram of how a monitoring system is set up in a rainwater harvesting solar streetlight based on AI using Raspberry Pi 4 Model B as the processor. The system incorporates ACS712 (current sensor), Battery SOC sensor, DHT22 (temperature and humidity sensor), and TDS water quality sensor, along with an MCP3008 analog-to-digital converter (ADC) that offers an easy interface to the components with Raspberry Pi. The current taken from the load and battery to the solar panel is measured using ACS712 current sensor where best energy management is well catered for.

SOC sensor is designed to monitor and measure the state of charge which helps the system compute the battery life and performance. DHT22 sensor offers real time temperature and humidity that are extremely important for the process of environmental monitoring and how they contribute in solar energy generation. Also, TDS sensor aids in judging how pure the rainwater collected is so one can determine if it can be used for irrigation and drinking.

There is no on-board analog input in Raspberry Pi 4; therefore, MCP3008 ADC helps in the conversion of analog sensor outputs into digital values in order to make it easy for interfacing with the Raspberry Pi GPIO pins. SPI protocol is used for Raspberry Pi to talk to MCP3008 in an effort to move data effectively and at high speed. The system also includes real-time cloud monitoring and data logging, realized through ESP8266/ESP32 Wi-Fi module uploading sensor data to IoT platforms such as Firebase or Thingspeak for remote processing and AI-driven predictive analysis. This smart circuit design is enabled to facilitate smart street lighting, smart energy metering, and water quality monitoring, thereby making it an immensely useful and sustainable smart infrastructure solution. Leveraging the AI-driven insights, the platform is enabled to identify power instability, predict battery ageing, maximize energy from solar panels, and track water resource planning, thereby leading the green and sustainable city infrastructure.

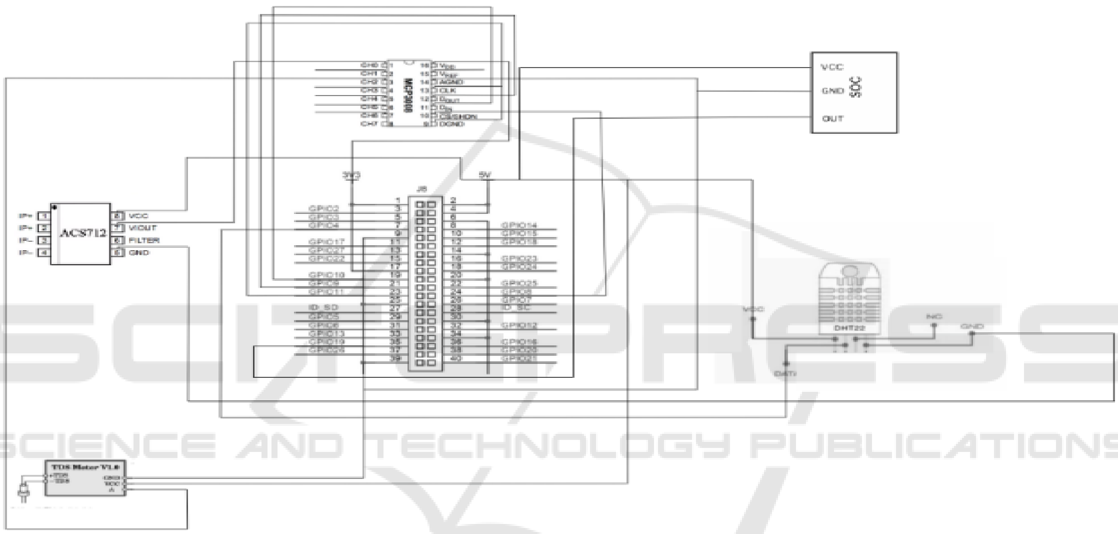

Figure 2: Circuit Diagram.

3.6 Proposed Solution

This design aims to create a multi-purpose solar streetlight that combines rainwater harvesting, AI-based monitoring, and increased solar energy output using simulation-based analysis. The system includes four solar panels, each with a 12V, 25W rating, placed in four disparate directions on a cone-shaped tip atop the pole. This innovative design has two functions by providing optimum light absorption for energy production while, at the same time, harvesting rainwater into a storage tank. The rainwater stored can be employed for business use in public spaces, and in urban and rural areas, an intrinsic filtration unit renders it fit for human consumption. To guarantee effective system operation and resource utilization, an AI-powered monitoring system is integrated to monitor solar energy generation, battery condition, water levels, and weather conditions. The AI platform uses virtual sensor data from modules like the ACS712 current sensor (solar panel and battery monitoring), battery SOC sensor (charge level monitoring), HC-SR04 ultrasonic sensor (water level sensing), TDS sensor (water quality analysis), and DHT22 temperature & humidity sensor (environment monitoring). The data is processed through machine learning algorithms to identify anomalies, project power consumption patterns, and enhance system efficiency in a simulated environment.

The double-chambered pole, one for water passage and another for electrical cable, provides appropriate storing, filtering, and secure energy transfer. A 12V solar charge controller is emulated to manage power flow between the solar panels, 12V battery, and the loads. The controller limits overcharging, deep discharge, and voltage fluctuations, and offers real-time power status indicators for AI-based performance analysis. The accumulated solar power is thereafter diverted for mobile charging and street lighting by a DC-to-DC converter for stepping down the voltage from 12V to 5V to facilitate the charging of mobile phones and other small electronic equipment through USB interfaces. Through simulation tests, AI-based models evaluate energy efficiency, environmental adaptability, and power optimization and enable performance checks under varying weather conditions and load conditions. This makes the system scalable, sustainable, and optimized prior to actual implementation in the real world. By integrating AI monitoring with renewable energy and water resource management, this smart solar streetlight system provides a smart, green, and community-focused infrastructure solution.

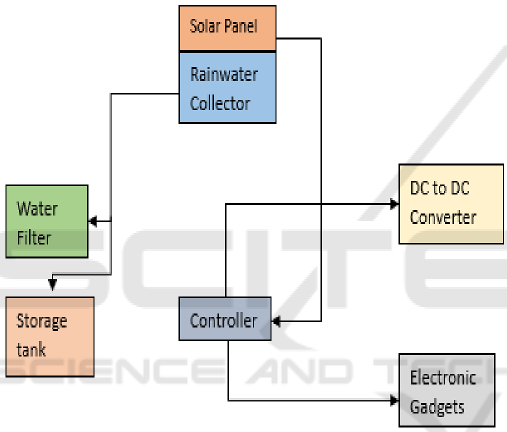

Figure 3: Block Diagram.

A hybrid simulation-based arrangement of utilizing solar energy and rainwater with AI based monitoring that helps in effective utilization of resources is depicted in form of a Figure 3 block diagram. A solar panel generates electricity, with a controller that regulates power to prevent excess variation, while a rainwater collector directs water from a filtration unit into a storage unit. Electronic appliances and lighting are supplied with stable power by means of a DC-to-DC converter. The AI monitoring system use real-time analytical data to test energy efficiency, battery levels, water levels, and power consumption to improve energy flow, detect abnormalities, and predict maintenance needs, Guide. To implement the support of the system, I constructed the system you can see now with the help of some specific data. This approach enhances sustainability and efficiency before actual implementation.

4 RESULTS AND EVALUATION

The solar streetlight system with integrated AI was simulated and tested successfully, showcasing immense energy efficiency, reliability, and sustainability. Simulation-based methodology proved the system effective in maximizing the use of solar energy, managing power distribution, and effectively handling water resources. The system comprising four 12V, 25W solar panels captured and converted solar energy efficiently under changing environmental conditions and provided continuous power supply even at low light. The 12V battery storage system, regulated by a solar charge controller, held the optimal charges, avoiding deep discharge and overcharging. Simulation of the DC-DC converter ensured that the surplus energy was effectively diverted to mobile charging use, promoting multi-functionality to the system. The rainwater harvesting system, simulated through the use of HC-SR04 ultrasonic sensors for monitoring the water level and TDS sensors for water purity monitoring, accurately proved efficient collection and purification procedures.

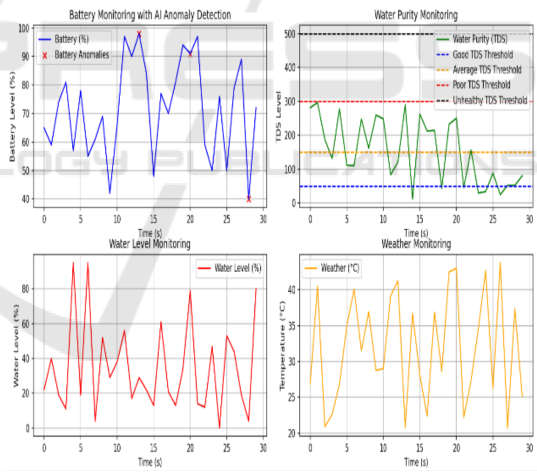

Figure 4: Simulated Graph.

The AI monitoring system with the aid of machine learning algorithms successfully processed sensor readings from ACS712 (current), SOC (charge of the battery), HC-SR04 (level of water), and TDS (purity of water). The AI model successfully identified anomalies in performance, regulated the flow of energy, and scheduled maintenance, thus providing reliability and long-term functionality to the system. The successful simulation outputs in Figure 4 ensure that this AI-driven solar streetlight system is scalable and applicable to smart urban and rural infrastructure projects.

5 DISCUSSION

Results of these simulations show that, due to the high technology usage of the proposed IoT-enabled solar streetlight system, an efficient, smart, specialized, and sustainable solution in comparison with the existing solar streetlights can be realized. With AI-based monitoring in real time, the system effectively optimizes energy consumption while improving power management, guaranteeing that resources are used optimally. Unlike traditional models with merely basic lighting application, the proposed system adopted multi-functional features such as mobile charging, rave water collection and predictive analytics, therefore a self-supported and intelligent infrastructure solution. Incorporation of machine learning algorithms enables the system with a much larger coverage area for inefficient generation of solar energy, predictive maintenance for battery deterioration and optimizing water availability.

Conducting AI-based analysis is for simulation validation to show that system can deployed for real-time applications allowing reduced usage of fossil fuels and espoused solar energy. More renewable energy and use of sustainable resources would increase while providing a true alternative using AI-tech simulation in solar systems. The simulated validated AI-enabled solar streetlight system is thus a more efficient, reliable and sustainable scalable & future-proof solution for smart city developments and rural electrification ventures.

6 CONCLUSIONS

The suggested AI-integrated solar streetlight system promotes energy efficiency, dependability, and multifunctionality using simulation-based analysis. Using four 12V, 25W solar panels mounted on a cone-shaped design, the system offers maximum solar absorption with the integration of rainwater harvesting for public and commercial applications. The monitoring system powered by AI ensures optimized flow of energy, battery storage, and water management, providing real-time performance observation and predictive maintenance. A 12V solar charge controller and storage battery ensure a continuous power supply, even during cloudy weather. The DC-DC converter allows maximum utilization of excess solar power for mobile charging, and hence the system is ideal for urban as well as rural applications. The double-compartment pole design enhances functionality and maintenance by ensuring effective electrical wiring and water storage.

The AI platform detects anomalies, controls power distribution, and predicts maintenance needs, thus achieving sustainability and resource-efficient use. Simulation results confirm that the system effectively reduces energy wastage, optimizes renewable energy utilization, and enables smart infrastructure development. Equipped with lighting, mobile charging, and water conservation features, this AI-powered solar streetlight is an innovative and scalable solution for sustainable urban and rural development.

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